SOME CALCULATIONS OF THE LATERAL DYNAMIC STABILITY CHARACTERISTICS

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Utilizing the results of the wind-tunnel tests of an X-15 configuration reported in the previous paper by Herbert W. Ridyard, Robert W. Dunning, and E. W. Johnston, analytical investigations of the airplane dynamic lateral behavior are being conducted for high altitudes where aerodynamic damping is low, and difficulty in controlling the airplane can be expected. The purpose of this study is to show some calculated lateral response characteristics of a configuration without dampers for two speed-brake conditions. Stability augmentation was not considered since it would be desirable to have the airplane flyable in the event of failure of dampers. Results will be presented of Dutch roll characteristics and lateral response to small yawing- and rolling-moment inputs 5
for a Mach number of 6.86 and altitude of 100,000 feet. The rotary derivatives have been neglected in this study because they have insignificant effects at the speed and attitude considered.

The following table shows the burnout weight and moments of inertia used in this investigation:

Weight, lb	10,443
Moment of inertia about principal X-axis, slug-ft^2	2,800
Moment of inertia about principal Y-axis, slug-ft^2	50,000
Moment of inertia about principal Z-axis, slug-ft^2	52,000

These values were obtained from early estimates and are somewhat smaller than current weight and inertias. It should be noted that the roll moment of inertia is only about 1/20 the pitch and yaw inertias and follows the trend of other high-speed aircraft.

In addition to inertias, the aerodynamic sideslip derivatives are important in determining airplane lateral motions. For this analysis the experimental results presented in the previous paper by Ridyard, Dunning, and Johnston for configuration 2 were used. In figure 1 the static lateral stability derivatives C_{Y_β}, directional stability C_{n_β}, and effective dihedral C_{l_β} for this configuration are presented for two speed-brake positions, one in which the brakes are deflected to form a wedge and the other in which the brakes are fully open 45°. In the present paper these brake positions are identified by the notation "wedge" and "open." The wedge configuration has about zero directional stability and small effective dihedral for all angles of attack, whereas the brakes-open configuration has large directional stability and an effective dihedral which is large at $\alpha = 0^\circ$ and decreases with angle of attack. Stability results will be shown for the extreme angles of attack, 0° and 24°.

These inertia and aerodynamic data then were used to determine the characteristics of Dutch roll, the oscillatory mode of lateral motion. Past experience showed that the Dutch roll characteristics which have the most effect on airplane lateral motions and pilots' opinions of the airplane are period, damping, and roll-to-sideslip ratio. In figure 2, results are presented of period and roll-to-sideslip ratio for an angle of attack of 0° as a function of directional stability and effective dihedral. No damping results are shown as the airplane has poor damping for any combination of C_{n_β} amd C_{l_β}. The constant-period lines are horizontal since period is a function only of directional stability for an angle of attack of 0°. These small periods, 1.5 and 3 seconds, coupled with poor damping, produce a Dutch roll oscillation which has been found to be objectionable to pilots in the past.

The radial lines shown are curves of constant roll-to-sideslip ratios, $|\varphi/\beta| = 4$ and $|\varphi/\beta| = 15$. From flight tests at low altitudes, it has been reported that pilots prefer airplanes having small roll-to-sideslip ratios. In fact, roll-to-sideslip ratios greater than 4, on the cross-hatched side of the curve, were intolerable regardless of the airplane damping.

The labeled points in figure 2 indicate the period and $|\varphi/\beta|$ characteristics for the wedge and fully opened speed-brake conditions. The wedge configuration is directionally unstable and hence divergent at this angle of attack. The brakes-open configuration has a large amount of directional stability and effective dihedral, a period of about 1 second, and a roll-to-sideslip ratio of about 5. From this figure it can be seen that an airplane configuration which lies in the region of moderate C_{n_β} and small C_{l_β} is desirable.

These results were for an angle of attack of 0° but flight at high angles of attack is also contemplated on some flight plans. For 24° angle of attack figure 3 shows the Dutch roll characteristics. The period curves, which were horizontal in the previous figure, now have a large slope due to the effect of principal axis inclination. Both the brakes-open and wedge configurations have a small period at this angle of attack, the wedge obtaining its small value from the contribution of effective dihedral and principal axis inclination. In fact, even for some negative values of C_{n_β}, the response is oscillatory and the periods small.

The roll-to-sideslip curves remain radial lines but the curve for 4 has shifted around into the lower quadrant. The smaller $|\varphi/\beta|$ values at $\alpha = 24^{\circ}$ indicate that the lateral-control problem would be considerably eased at higher angles of attack.

After investigating the Dutch roll characteristics, calculations were made of the airplane motion in response to step yawing and rolling moments. An immediate consideration for high-altitude flight was the possibility of roll coupling occurring even for small rolling velocities. Five-degree-of-freedom calculations of airplane motions showed coupling effects for large rolling maneuvers, rolls of 180° or 360°, but motions in bank up to 90° were free of inertia coupling. For the purpose of controlling the airplane over a high-altitude trajectory, it was assumed that most maneuvers would not exceed bank angles of 90° and hence the motions were computed from three-degree-of-freedom linear equations.

The following three figures (figs. 4, 5, and 6) will show the effect of configuration on airplane lateral motions. Figure 4 presents the airplane bank and sideslip motions in response to a step yawing moment ($C_n = -0.0017$). Results are for angles of attack of 0° and 24°.

The responses for $\alpha = 0^{\circ}$ are rapidly divergent for the wedge configuration because of its directional instability. With the brakes open 45°, the sideslip motion is small due to the large value of directional stability and one might expect the roll motion due to dihedral effect to be small. However, the bank motion is severe (80° in less than 3 seconds) as a result of the large effective dihedral of this configuration and the small rolling inertia. Equivalent rudder deflection for this configuration was 0.4° or about 7 percent of available rudder, assuming no rolling moments are produced by rudder deflection, and indicates a large rolling sensitivity to yaw controls for this Mach number and altitude.

For an angle of attack of 24°, the rolling sensitivity to yaw control is reduced for both brake-position configurations. For the wedge the reduction in bank angle results from the stabililizing effect of angle of attack in reducing the sideslip response. The sideslip motion for the brakes-open configuration is unchanged but the roll motion is much smaller due to the variation of dihedral effect with angle of attack. Hence, the response of both configurations to a yawing-moment input is improved by increasing angle of attack.

The other lateral control is the roll control (obtained by differential deflection of horizontal tail), and figure 5 shows the airplane response to a rolling-moment input ($C_l = -0.00036$ or about 2° of control deflection, which is 8 percent of the available control).

At an angle of attack of 0° both tail configurations roll because of the rolling-moment input but the wedge configuration is unstable and is divergent in sideslip.

For $\alpha = 24^{\circ}$ the rolling motion of the wedge configuration is slow, since dihedral effect is bucking the control rolling moment. In fact, at low angles of attack, where the wedge configuration was shown to be directionally unstable but the response periodic, the final roll motion is in the positive direction, or opposite to the way the pilot is attempting to bank the airplane. Hence, to insure rolling performance of the airplane at high angles of attack, a moderate amount of directional stability, as well as small effective dihedral, is required.

The results discussed in figures 4 and 5 were motions due to pure yawing- or rolling-moment inputs. Generally, airplane lateral controls produce both rolling and yawing moments, that is, ailerons produce a yawing moment and rudders produce a rolling moment in addition to the primary control moments. The actual response due to horizontal-tail differential deflection or rudder deflection can be determined by superimposing the results of figures 4 and 5 in accordance with the control effectiveness derivatives. The actual aileron response is little different from these results in that differential deflection of the horizontal tail for roll produces a small favorable yawing moment which increases rolling performance by a small amount.

The response to rudder deflection for the brakes-open configuration is presented in figure 6. For this configuration the entire upper vertical fin was used as a rudder and was shown in the previous paper by Ridyard, Dunning, and Johnston to produce a large rolling moment. Notice that the resulting roll is positive or opposite to the roll direction that the pilot expects from dihedral effect. The positive roll results because the contribution of rolling moment due to rudder deflection exceeds that of dihedral effect.

Also, in applying rudder to reduce an initial sideslip angle to zero, a positive rolling moment produced by rudder deflection would require the pilot to apply additional aileron to prevent rolling, which he might interpret as a loss of aileron power. This is particularly critical for this brakes-open configuration for $\alpha = 0^{\circ}$, for which 1° of rudder produces about 10 times as much rolling moment as 1° of aileron. Hence a configuration for which the rolling moment produced by rudder deflection is small and favorable is desirable.

The following comments regarding the lateral stability and control of configuration 2 can be made for a Mach number of 6.86 and altitude of 100,000 feet:

1. Roll-to-sideslip ratios are large at an angle of attack of 0° as a result of high effective dihedral.

2. Lateral response of the wedge configuration is unsatisfactory for all angles of attack as a result of insufficient directional stability.

3. The airplane is very sensitive in roll to yawing-moment inputs at an angle of attack of 0°.

4. Rolling moment due to rudder deflection is large and can have adverse effects on roll control.

At this time other vertical tail and rudder configurations are being investigated in an attempt to improve directional stability and reduce the effective dihedral and adverse roll of the rudder.

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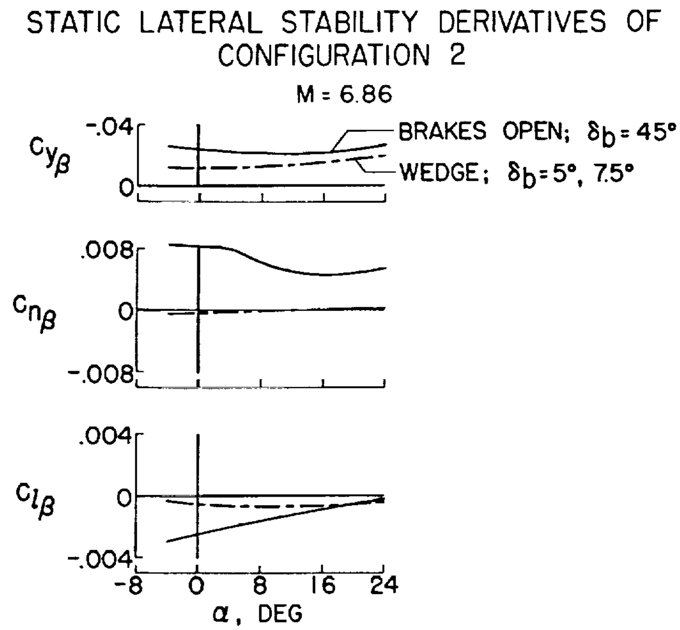
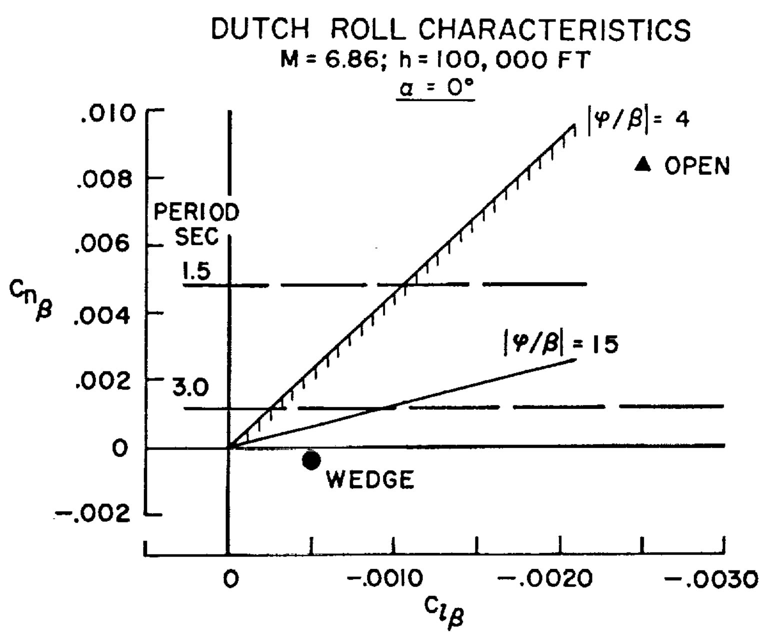


Figure 1



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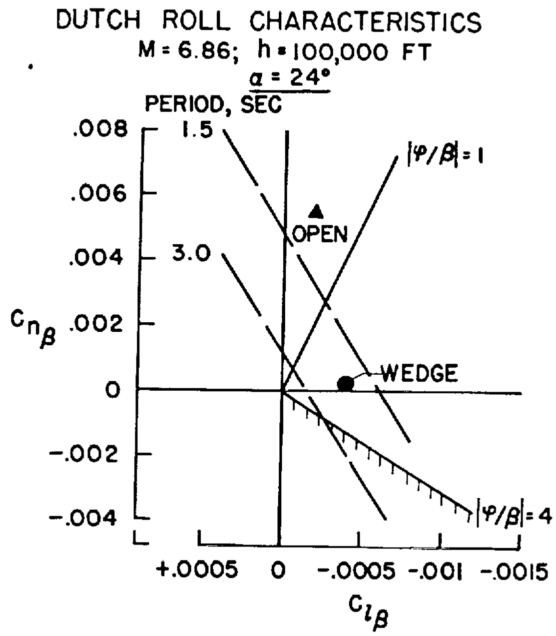

Figure 3

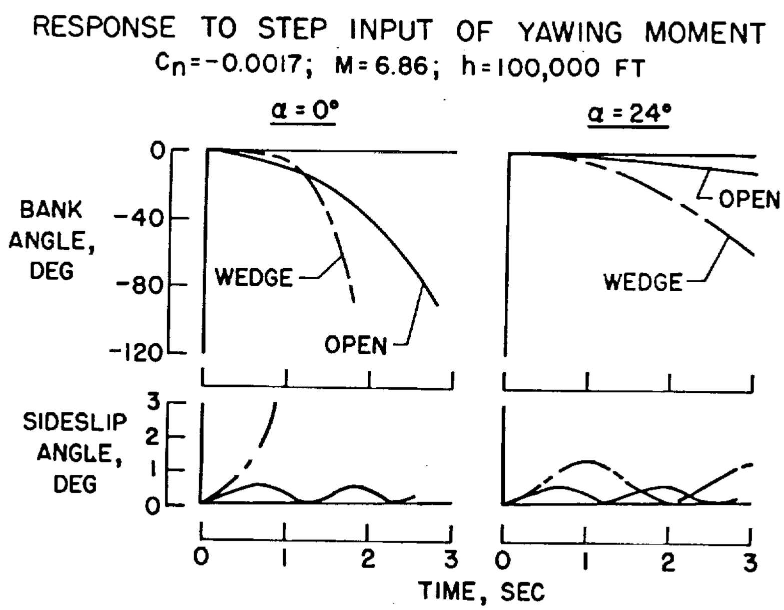

Figure 4

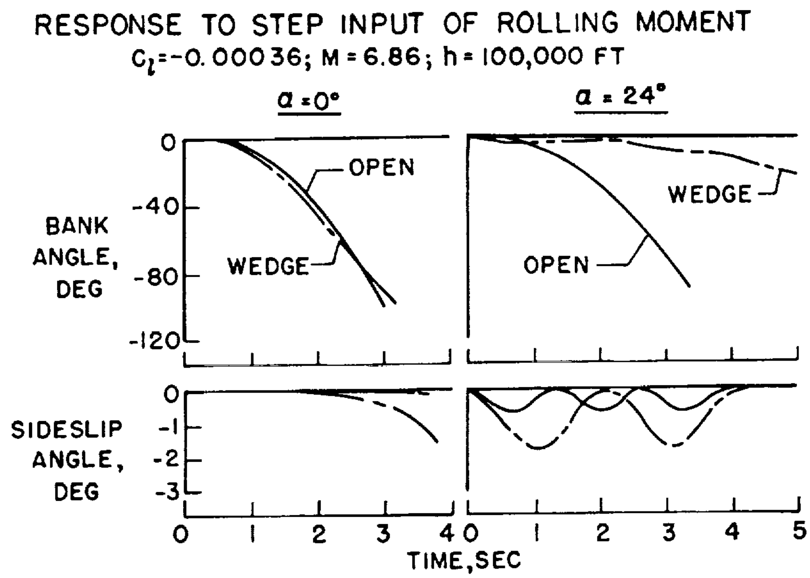

Figure 5

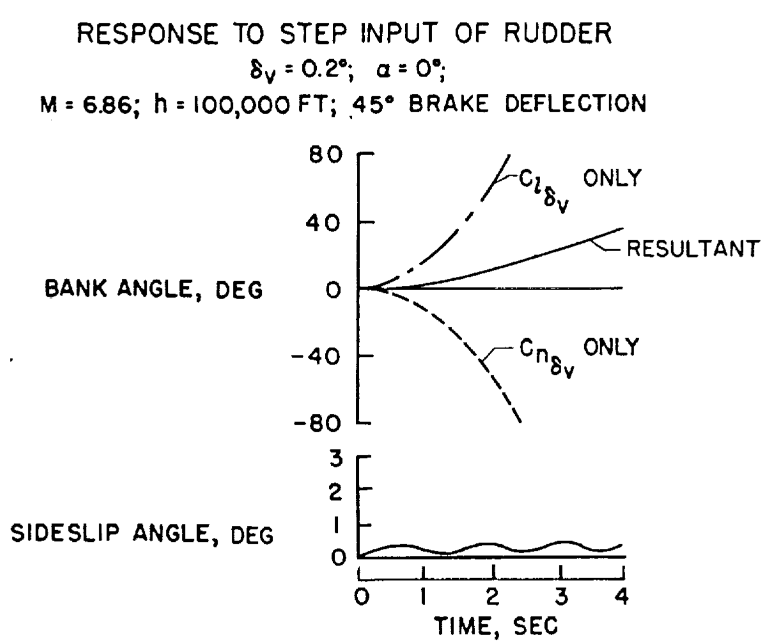

Figure 6